# UTILITY CARRIER DEVELOPMENT PROGRAM. REPORT I. LIMITED STUDY OF EFFECTS OF JUNGLE TRAIL CHARACTERISTICS ON PERFORMANCE OF SELECTED SELF-PROPELLED VEHICLES

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Army Engineer Waterways Experiment Station
Vicksburg, Mississippi

October 1969

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# UTILITY CARRIER DEVELOPMENT PROGRAM

Report 1

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by

E. S. Rush



October 1969

Sponsored by

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Vicksburg, Mississippi

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13. ABSTRACT

A series of reports prepared by the Joint Thai-U. S. Military Research and Development Center were reviewed to determine the effects of jungle trail features, especially trail width, on performance of the M274 1/2-ton Carrier and two concept vehicles, one 65 in. and the other 89 in. wide. In these reports it was generally concluded that vehicles whose widths approached 90 in. experienced difficulty along the trails. Overhanging vegetation and fallen trees restricted driver visibility and damaged windshields of vehicles whose heights were about 80 in. or more. Slippery soils and steep streambanks plagued trail operations; deep ruts in the trail surface also caused considerable problems. Nonamphibious vehicles experienced numerous engine failures in fording operations. Streams deep enough to float vehicles had current velocities less than 3 mph. Based on the review of these reports, the following suggestions are made. The vehicle should be less than 90 in. wide and less than 80 in. high. Ground clearance should be greater than 18 in. and the underbody should be smooth. The turning radius should be less than 15 ft. The traction elements should have the traction capabilities of a track and the low maintenance requirements of a wheel. The vehicle should be amphibious and should be able to maintain directional control against a current velocity of 3 mph. However, if nonamphibious but equipped with waterproof ignition and exhaust systems, the vehicle would meet approximately 90 percent of the requirements for water crossing. The vehicle should have a high-capacity winch and power steering or easy steering capabilities. Ground pressures in the order of 2 psi or less are desirable for soft soils that may be encountered.

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ARMY-MRC VICKSBURG, MISS.

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## Foreword

In June 1967 the U. S. Army Tank-Automotive Command (TACOM) conducted a study of proposed draft military requirements for 1/2- and 3/4-ton logistical carriers. This study revealed that seven draft requirements existed; five requirements were for new vehicles and two requirements were for replacements for the 1/2-ton M274. In August 1968, the U. S. Marine Corps requested that TACOM begin a 1/2-ton concept program to replace the M274. Mr. J. P. Carr, U. S. Army Materiel Command, was assigned as project manager of the program.

The limited study reported herein was requested by Mr. Carr. The purpose of the study was to obtain some evidence for guidance in establishing maximum widths of the concept vehicles. The study was conducted in March 1969 by personnel of the Vehicle Studies Branch (VSB), Mobility and Environmental (M&E) Division, U. S. Army Engineer Waterways Experiment Station (WES), under the general supervision of Messrs. W. G. Shockley and S. J. Knight, Chief and Assistant Chief, respectively, of the M&E Division, and Mr. A. A. Rula, Chief, VSB. The study was conducted by Messrs. J. G. Kennedy, engineer, and E. S. Rush, Chief, Soil-Vehicle Studies Section, VSB. The report was written by Mr. Rush.

Director of WES during the conduct of the study and the preparation of the report was COL Levi A. Brown, CE. Technical Director was Mr. Fred R. Brown.

Contents

## Conversion Factors, British to Metric Units of Measurement

British units of measurement used in this report can be converted to metric units as follows:

| Multiply | By | To Obtain |
|---|---|---|
| inches | 2.54 | centimeters |
| feet | 0.3048 | meters |
| yards | 0.9144 | meters |
| miles | 1.609344 | kilometers |
| miles per hour | 1.609344 | kilometers per hour |
| pounds per square inch | 0.070307 | kilograms per square centimeter |
| tons (2000 lb) | 907.185 | kilograms |

## Summary

A series of reports prepared by the Joint Thai-U. S. Military Research and Development Center were reviewed to determine the effects of jungle trail features, especially trail width, on performance of the M274 1/2-ton Carrier and two concept vehicles, one 65 in. and the other 80 in. wide. In these reports it was generally concluded that vehicles whose widths approached 90 in. experienced difficulty along the trails. Overhanging vegetation and fallen trees restricted driver visibility and damaged windshields of vehicles whose heights were about 80 in. or more. Slippery soils and steep streambanks plagued trail operations; deep ruts in the trail surface also caused considerable problems. Nonamphibious vehicles experienced numerous engine failures in fording operations. Streams deep enough to float vehicles had current velocities less than 3 mph.

Based on the review of these reports, the following suggestions are made. The vehicle should be less than 90 in. wide and less than 80 in. high. Ground clearance should be greater than 18 in. and the underbody should be smooth. The turning radius should be less than 15 ft. The traction elements should have the traction capabilities of a track and the low maintenance requirements of a wheel. The vehicle should be amphibious and should be able to maintain directional control against a current velocity of 3 mph. However, if nonamphibious but equipped with waterproof ignition and exhaust systems, the vehicle would meet approximately 90 percent of the requirements for water crossing. The vehicle should have a high-capacity winch and power steering or easy steering capabilities. Ground pressures in the order of 2 psi or less are desirable for soft soils that may be encountered.

# UTILITY CARRIER DEVELOPMENT PROGRAM

## LIMITED STUDY OF EFFECTS OF JUNGLE TRAIL CHARACTERISTICS ON PERFORMANCE OF SELECTED SELF-PROPELLED VEHICLES

## Introduction

1. This limited study was prompted by a request from Mr. J. P. Carr, U. S. Army Materiel Command, that the U. S. Army Engineer Waterways Experiment Station determine the effects of jungle trail features, especially trail width, on performance of the M274 1/2-ton Carrier and two concept vehicles, one 65 in. and the other 80 in. wide.*

2. The most readily available source of information for the limited study was a series of reports prepared by the Joint Thai-U. S. Military Research and Development Center. The reports selected for review in this study are listed on pages 11 and 12.

3. In the review of these reports it was found that trail width was not the only factor affecting self-propelled vehicle performance; therefore, all jungle trail features and their effects on performance were examined. In many instances, the data were qualitative and inconclusive; but certain problems encountered in trail operations occurred frequently and can be assumed, with reasonable confidence, to be real problems.

## Definition of Jungle Trails

4. Based on the descriptions in the referenced reports, jungle trails for this study had the following characteristics. They had been developed by repeated traffic of two-wheel carts drawn by one or two bullocks and of pack ponies and humans on foot. They were located where distances between two places were the shortest, soil and terrain conditions permitted the easiest travel, and streams could be crossed by fording or

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* A table of factors for converting British units of measurement to metric units is presented on page vii.

spanned by simple bridges. Trails were largely unimproved but had some crude log bridges across streams. Vegetation encroached along the sides of the trails, and fallen trees blocked traffic. Deep ruts created by traffic were seldom refilled; however, in some of the worst ruts, logs had been placed perpendicular to traffic, making a "corduroy" effect. Some trails had been used during dry seasons by self-propelled vehicles engaged in logging operations.

## Brief Trail Descriptions

5. The general locations of the trails considered are shown in fig. 1. Trail conditions as they were at the time the cited reports were written are described in the following paragraphs.

### Pran Buri Trail (references 1, 2, and 3)

6. Pran Buri Trail was an unimproved trail about 14 miles long. It had been used in studies to determine the effects of steering and width of vehicle on performance. There were 254 turns in the trail, ranging from gentle S-shape to extremely sharp U-turns (turn radii 35 to 50 ft). Trail widths varied from 8 to 15 ft, and in places the trail was deeply entrenched, with banks up to 4 ft high. The trail was almost completely shaded by overhanging vegetation, which in many places was low enough to reduce visibility. Grades generally ranged from 3 to 5 percent, with lengths up to 300 ft. One trail grade was 100 percent for a length of 35 ft. Streambank slopes were short and ranged up to 80 to 100 percent. At the time of testing, the trail surface in some areas was firm and smooth, but in other areas the surface was muddy and deeply rutted. The firm areas were usually covered with gravel or laterite spilled onto the trail from surrounding higher ground. Stream bottoms were composed of gravel, sand, and rock.

### Pakchong Trail (references 3, 4, 5, and 6)

7. Pakchong Trail was an unimproved cart trail typical of those used by villagers in the highlands. It was about 45 miles long and wide

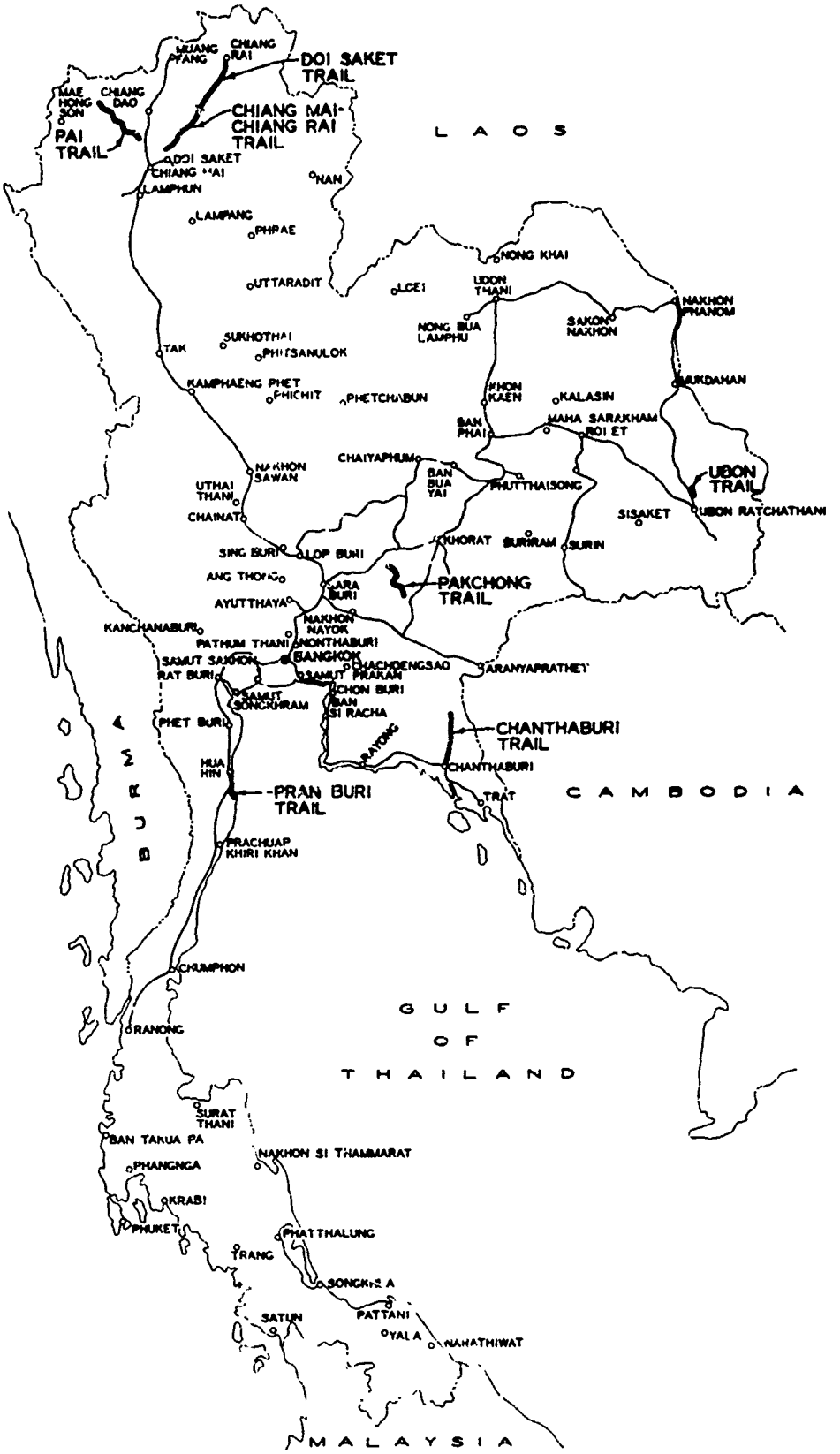


Fig. 1. Trail locations

enough to accommodate vehicles at least 8 ft wide. Deep ruts had been created during rainy season operations. Some ruts were 10 to 24 in. deep and 12 to 19 in. wide. Grades varied, with maximum slopes of about 20 percent. Overhanging vegetation restricted visibility, and was often so low as to strike a vehicle as it moved along the trail. There were seven log bridges over streams crossing the trail. Eighteen other small streams crossing the trail were not bridged, but they could be easily forded. One stream of significance was 70 ft wide and about 6 ft deep; current velocity was 0.7 mph. The streambanks were clay with 40 percent slope.

Chanthaburi Trail (reference 2)

8. Chanthaburi Trail was 54 miles long, and according to the author of reference 2 it was the most rugged Thailand jungle trail encountered in 1-1/2 years of vehicle testing. The first 10 miles of trail was being widened and resurfaced, but soft soils, streams, slopes, and overhanging vegetation made the rest of the trail difficult to travel. There were 55 streams crossing the trail; they ranged from 12 to 90 ft wide and 1/2 to 2 ft deep. Streambank slopes averaged 35 percent, with a maximum of 58 percent.

Doi Saket Trail (reference 6)

9. Doi Saket Trail in the mountains of northern Thailand was 76 miles long. During the wet season the principal means of transportation was by bullock carts or pack ponies. About half of the trail was through mountains and the other half through valleys between mountains. The soil was primarily silty clay. Rut depths ranged from zero to 2 ft. Vegetation was not so dense as that on the Pakchong Trail. The numbers of occurrences of a given slope range were as follows: 57 slopes from 20 to 30 percent; 52 slopes from 30 to 40 percent; 10 slopes from 40 to 50 percent; and 18 slopes greater than 50 percent. The steepest slopes were short slopes along streambanks. There were 114 streams crossing the trail; 60 could be forded and 54 were bridged by logs. One major river (180 yd wide with a current velocity of 2.4 mph) crossed the trail. There was no bridge; but amphibious vehicles could negotiate the river.

Pai Trail (reference 6)

10. This 31.4-mile-long trail was in the mountainous terrain of

north Thailand. Soil types were laterite and clay. Twelve streams crossed the trail; six streams could be forded, and six streams were bridged by logs. The trail was muddy for about 2 miles, and rut depths ranged up to 20 in. Numbers of occurrences of a given slope range were as follows: 10 slopes from 20 to 30 percent; 27 slopes from 30 to 40 percent; 2 slopes from 40 to 50 percent; and 8 slopes greater than 50 percent (streambanks).

Ubon Trail (reference 3)

11. This trail was just over 2 miles long. The first half had been widened recently by construction equipment; the last half was largely undisturbed and was considered to be a typical bullock cart trail. The top 18 in. of trail surface was compacted and firm, but in some areas the soil below this depth was soft. The trail was bordered by woods and undergrowth for about a mile and by rice paddies for about a mile. Two streams crossed the trail; one was deep enough to float amphibious vehicles.

Chiang Mai-Chiang Rai Trail (reference 7)

12. This trail was 33 miles long and wound through rough, mountainous country containing many streams and rocky ravines. Vegetation was very dense in places, crowding both sides of the trail and seriously limiting visibility, especially at curves. Environmental factors affecting vehicle performance were water crossings, severe slopes, deep ruts--all combined with soft and slippery soil. Deep ruts were created by heavily loaded local trucks traveling after heavy rains. Some rut depths were up to 30 in.; however, most were about 10 in. Slopes from 30 to 40 percent with slope lengths from 50 to 100 ft occurred frequently along the trail. The maximum slope was 50 percent for a distance of 100 ft. The average stream was 30 ft wide and 18 in. deep. The largest stream was 80 ft wide and 3 ft deep, with an average current flow of 2.7 mph.

## Vehicles, Vehicle Factors, and Trails Tested

13. The following tabulation lists vehicle name, width, length, and turn radius, and the trail on which the vehicle was tested. These factors were considered in the evaluation of the effects of jungle trails on vehicle performance.

| Vehicle Name | Length/ Width in. | Turn Radius ft | Trail |
|---|---|---|---|
| Gama Goat | 200/80 | 15 | Pran Buri |
| Jiger | 76/51 | 5 | Pakchong |
| Spryte | 155/79 | 15 | Pakchong |
| XM561 2A | 230/84 | 30 | Pran Buri |
| XM561 2B | 230/100 | 36 | Pran Buri |
| M37 | 189/74 | 25 | Chanthaburi |
| FV432MK2 | 201/111 | -- | |
| FV437 | 252/113 | 9 | |
| M113-1/2 | 183/94 | 24 | |
| Stalwart | 250/103 | 25 | Ubon |
| M551 | 248/110 | 31 | Pakchong |
| XM561 | 230/100 | 36 | Chiang Mai |
| XM571 | 234/64 | 20 | |
| M116 | 188/82 | 22* | |
| Trucks | | | |
| 1/4-ton, standard | 131/63 | 18 | |
| 1/4-ton, low-pressure pneumatic tire | 131/69 | 24* | Chiang Mai |
| 3/4-ton, standard | 200/79 | 25 | |
| 3/4-ton, low-pressure pneumatic tire | 200/94 | 31* | |
| XM571 | 234/64 | 20 | Pran Buri |
| M116 | 188/82 | 22* | Pakchong |
| | | | Doi Saket |
| | | | Pai |

* Estimated.

## Results of Vehicle Performance on Jungle Trails

14. Results of vehicle performance on jungle trails as compiled from the referenced reports are presented below. In some instances, the reports indicate that the trail was traversed in both directions. However, in tabulating the number of occurrences of an item (e.g. stream crossings) along a trail, only one direction was counted. Descriptions of events encountered along the trail were also handled in the same manner.

### Total trail distances traveled

15. The following tabulation lists the trail, number of vehicles tested, and total miles traveled by all vehicles.

| Trail | Number of Vehicles | Distance Traveled miles |
|---|---|---|
| Pran Buri | 6 | 96 |
| Pakchong | 10 | 322 |
| Chanthaburi | 3 | 162 |
| Doi Saket | 2 | 152 |
| Pai | 2 | 62 |
| Ubon | 8 | 16 |
| Chiang Mai | 4 | 132 |
| | Total | 942 |

Numbers of occurrences of immobilization

16. The causes of immobilizations, numbers of occurrences, and miles traveled per occurrence are tabulated below.

| Cause of Immobilization | Occurrences No. | Occurrences % of Total | Total Miles per Number of Immobilizations |
|---|---|---|---|
| Deep ruts (track or wheel failure, steering failure) | 29 | 30.2 | 942/29 = 32.5 |
| Bogged down (soft soil) | 31 | 32.3 | 942/31 = 30.4 |
| Loss of traction (slopes on streambanks) | 15 | 15.6 | 942/15 = 62.8 |
| Engine drowned out (stream fording) | 21 | 21.9 | 942/21 = 44.8 |
| Total | 96 | | 942/96 = 9.6 |

17. The tabulation above gives some indication of the probability of occurrence of an immobilization of some type in the 942 miles of operation with the 17 vehicle types listed in paragraph 13. The criterion of miles per immobilization may be misleading when considered by itself; for example, 11 of the 31 bogged-down immobilizations occurred in the 2-mile-long Ubon Trail. Also, percent of occurrence and average miles per immobilization should not be interpreted to apply to cross-country operation. It should be kept in mind that jungle trails, although largely unimproved, were originally selected on the basis of best soil and terrain conditions encountered when going from one place to another.

## Notes and Conclusions from Referenced Reports

18. Notes and conclusions from the referenced reports that were

considered pertinent to this study are given below.

Reference 1 (Gama Goat)

19. Trail turns caused no immobilization. Turns decreased vehicle speed because of restricted visibility due to high banks and vegetation. Continuous steering caused operator fatigue. Grades were negotiated without difficulty. Old ruts and underbody drag taxed the vehicle to the maximum and had a greater effect upon vehicle trail performance than did vegetation, curves, or gradient.

Reference 2
(XM561 2A, XM561 2B, and M37)

20. The performance of the M37 on jungle trails was unsatisfactory since it is not amphibious and cannot develop adequate traction in soft soil. The standard XM561 could not develop sufficient traction in the soft soil and could not be steered out of old ruts; therefore, it was not entirely satisfactory in the trail operations. The modified XM561 with low-pressure pneumatic tires showed excellent traction capabilities, but the vehicle is too wide for trail operations. It was recommended that the modified XM561 be equipped with a jungle kit consisting of brush guard, stronger carrier boxes, winch, and flexible fender extension (for wider tires).

Reference 3 (Mudlark)

21. Generally, the FV432, FV437, Stalwart, and M551 were too wide and too heavy to operate on the jungle trails. The M113-1/2 could negotiate most trails if careful driving techniques were employed. The XM571 and M116 had no difficulty on the trails.

Reference 4 (Jiger)

22. Average Jiger speed throughout 17 miles of trail was 5.5 mph. During the wet season, jeeps and Land Rovers could not negotiate the trail, and the average speed of 2-1/2-ton trucks over the 17 miles was 1.4 mph.

Reference 5 (Spryte)

23. Dense vegetation overhanging trails restricted driver visibility and vehicle movement. Deep ruts were bridged to prevent track damage or throwing. Amphibious qualities were a necessity. However, the trail was wide enough to accommodate the vehicle.

Reference 6 (XM571 and M116)

24. It was recommended that cab and windshield assemblies of the XM571 and M116 be strengthened for jungle trail operations. Trail surface conditions caused track throwing on a few occasions. The two vehicles are capable of traveling trails in all seasons in Thailand. In 290+ miles of jungle trail operations, the XM571 was immobilized only once and the M116 only twice because of slope or streambank conditions.

Reference 7 (1/4- and 3/4-ton trucks with standard and low-pressure pneumatic tires)

25. Engine failure during fording operations was the greatest immobilization problem with these vehicles. Low-pressure pneumatic tires did not increase their mobility on slippery soil surfaces, rock obstacles, and in deeply rutted surfaces. The 3/4-ton truck with low-pressure pneumatic tires was too wide for jungle trail operations.

## Discussion of Trail Characteristics in Other Environments

26. Jungle trails in remote tropical or semitropical environments, particularly those trails that are used by human- and animal-drawn carts, probably are similar to the jungle trails of Thailand described herein. Trail maintenance usually consists of clearing overhanging vegetation and vegetation encroaching from the sides, filling ruts with local material, or bridging local soft spots with logs or tree branches. Trails are maintained manually. On trails outside jungle areas, maintenance may not exist or may consist of trail surface stabilization in mountainous areas, construction of crude bridges, etc. Usually, the level of maintenance performed is just sufficient to ensure passage of vehicles used.

27. In developed countries such as the United States and those of Europe, frequently used unimproved trails are almost nonexistent. Where trails do exist, they are maintained largely by mechanical equipment to a level that will provide the desired performance. Trail widths range from 80 to 100 in. In developed countries trails may serve more than one purpose. They may be used for managing and harvesting timber and for fire

breaks or for quick access in case of forest fire. In areas where the surface drainage is good, trails are maintained; but in poorly drained areas where conventional vehicles rut deeply, specialized vehicles are employed.

28. Limited trail operations on military reservations of West Germany indicate that an M37 3/4-ton truck can travel over trails with ease except for crossing streams with soft soil banks. Vehicle speeds on trails are usually low because of irregular trail surfaces. On the seldom-used trails, grass cover may obscure the ground surface and require the driver to operate his vehicle at a slow, cautious speed.

29. In subarctic and arctic areas covered by organic soil, trails in low areas are usually difficult to negotiate in the summer without using specialized vehicles. For this reason, most travel in these areas is accomplished during the months of the year when the ground is frozen.

## Summary of Findings

30. Based on a review of the referenced reports, the following general statements are offered.

a. When vehicle widths approached 90 in., difficulty was experienced because of banks or vegetation on the sides of the trails in mountainous areas and because of soft soils in drainage ditches paralleling compacted trails in open areas.

b. Overhanging vegetation and fallen trees restricted driver visibility and damaged windshields of vehicles whose heights were about 80 in. or greater.

c. Slippery slopes and steep streambanks plagued trail operations more than any other terrain feature. Generally, the tracked vehicles had no problems, but all wheeled vehicles had problems except possibly the XM561 with large, low-pressure pneumatic tires. The large tires, however, made the vehicle too wide for most trail operations.

d. Deep ruts created during rainy season travel remained throughout the dry season. In both seasons, ruts caused immobilizations due to traction losses combined with underbody drag and to mechanical failures of track and wheel systems and steering linkages.

e. Nonamphibious vehicles experienced numerous engine failures (drowned out) in fording operations. In most cases the problem could have been eliminated by use of waterproof

ignition systems. In only a few instances were amphibious vehicles necessary. Streams encountered that were deep enough to float vehicles had current velocities less than 3 mph.

f. Winch systems for self-retrieval were suggested numerous times as an aid to better jungle trail operation.

## Suggested Vehicle Concept Design Considerations

31. Based on the review of reports describing jungle trail operations, it is suggested that a vehicle incorporating the following general specifications should be ideal for trail operations.

32. The vehicle should be less than 90 in. wide (the less the better) and less than 80 in. high. Ground clearance should be greater than 18 in. and the underbody should be smooth. The turning radius should be less than 25 ft. The traction elements should be rugged to withstand rough trail surfaces such as old, hardened ruts and rock outcrops. The traction elements should have the traction capabilities of a track and the low maintenance requirements of a wheel. The vehicle should be amphibious and maintain directional control against a 3-mph current velocity; however, if nonamphibious but equipped with waterproof ignition and exhaust systems, the vehicle would meet approximately 90 percent of the requirements for water crossing. It should have a high-capacity winch and power steering or easy steering capabilities. Ground pressures in the order of 2 psi or less are desirable for soft soils that may be encountered.

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